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(54) Refrigeration system

(57) The invention relates to a cascade type refrigeration system. The refrigeration system comprises a first closed refrigeration circuit (17) and a second closed refrigeration circuit (18). The two refrigeration circuits (17,18) are linked by means of a cascade heat exchanger (5) comprising the first condenser and the second

evaporator arranged so that the first condenser is cooled by means of the evaporation of the second liquid refrigerant in the second evaporator. The refrigeration system is characterised in that said first liquid refrigerant consist substantially of CO₂ and the first evaporator (3) is operating at pressures above 120 psig. The invention also relates to a method of refrigeration.

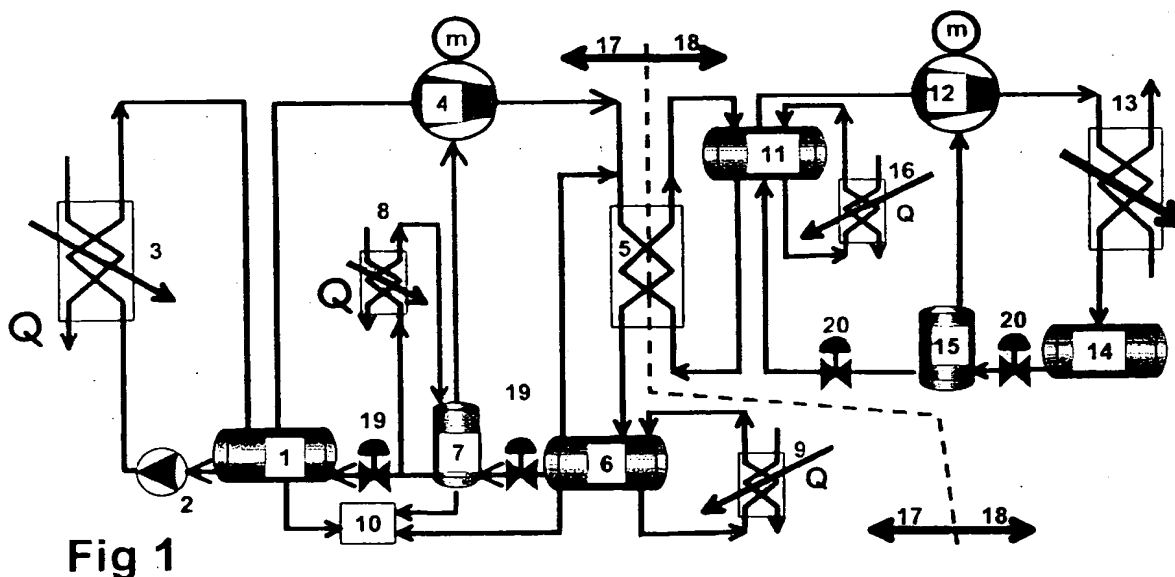


Fig 1

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Description

Field of the Invention

[0001] This invention relates to a refrigeration system comprising a first and a second closed refrigeration circuit, the second refrigeration circuit being arranged to refrigerate the first refrigeration circuit by means of a cascade heat exchange connection. The refrigeration system according to the invention provides an energy efficient refrigeration. The refrigeration system is particularly suitable for an application in the food industry. The invention also relates to a method of refrigeration.

Background to the Invention

[0002] The Refrigeration industry is faced with a number of issues that is making it more difficult to use conventional refrigerants and system designs. For environmental reasons, many of the popular synthetic refrigerants Chloro-Fluoro-Carbons (CFC's) can not be used due to their high Ozone Depletion Potential. Other refrigerants such as Hydro-Chloro-Fluoro- Carbons (e. g. HCFC-22) will soon also be phased out for the same reason. Also, the use of the new replacement refrigerants Hydro-Fluoro-Carbons(HFC's) may be restricted due to their high global warming potentials. In addition hereto, concerns about global warming are expected to raise an increasing pressure toward more energy efficient operations.

[0003] Historically, the most popular natural refrigerant has been Ammonia as it allows simple, efficient systems. In recent years, this has been the preferred industrial alternative to the CFC's and HCFC's. However, due to its toxicity, it is now coming under increasing pressure worldwide. In many countries, industrial ammonia refrigeration systems must now meet more rigorous chemical industry standards for management of safety. In some cases its use is being severely restricted, or even prevented.

[0004] Prior to the introduction of CFC's & HCFC's, CO₂ was widely used as a refrigerant, especially in applications where the toxicity of Ammonia was unacceptable. This was the case for example in shipboard refrigeration. However, these were single or multi stage compression systems where the refrigerant was condensed at very high pressures using air or water. Cascade systems were not used. This type of system had significant disadvantages due to very high working pressures in the condenser and a low critical temperature, limiting the temperature at which the CO₂ could be condensed. When the system was operated above this temperature (i.e. super-critical), efficiency was lower than alternative systems using CFC's, HCFC's or ammonia.

[0005] US patent No. 5,042,262 described a Food Freezer, which used CO₂ as a low temperature refrigerant, being cooled in cascade by another evaporating refrigerant operating at higher temperatures. US patent

No. 5,042,262 recommended pressures in the CO₂ evaporator to between 60.4 psig and 120 psig. It also recommended a pressure in the whole CO₂ system to 325 psig.

[0006] Investigation of this system has shown that the specifically recommended pressure limits in US patent No. 5,042,262 makes the system significantly less efficient than a conventional industrial refrigeration system. The users of the system will be operating below the 120 psig, which corresponds to -44°F (- 42°C) saturation temperature, and this is irrespective of the real temperature needed by the user. The effect of this is a higher power consumption than a conventional refrigeration plant, which operates only at the needed temperatures.

[0007] There is therefore a need for a refrigeration system using CO₂ as a refrigerant capable of working efficiently.

Summary of the Invention

[0008] Accordingly, in one aspect, the invention provides a refrigeration system. The refrigeration system comprises:

a first closed refrigeration circuit for containing a first refrigerant, comprising a first evaporator for evaporating first refrigerant liquid, a first compressor for compressing first refrigerant vapour, a first condenser for condensing the first refrigerant vapour, and a first control valve for controlling the pressure difference between the high pressure side and the low pressure side of the first circuit,
a second closed refrigeration circuit for containing a second refrigerant, comprising a second evaporator for evaporating second refrigerant liquid, a second compressor for compressing second refrigerant vapour, a second condenser for condensing the second refrigerant vapour, and a second control valve for controlling the pressure difference between the high pressure side and the low pressure side of the second circuit, and
a cascade heat exchanger comprising the first condenser and the second evaporator arranged so that the first condenser is cooled by means of the evaporation of the second refrigerant liquid in the second evaporator

characterised in that the first refrigerant consists substantially of CO₂ and the first evaporator is operating at pressures above 120 psig.

[0009] Surprisingly we have found that a high pressure CO₂ refrigeration system, operating in cascade with another refrigerant operating at a higher temperature, can be made at least as efficient as a conventional industrial refrigeration system, and in some cases more efficient.

[0010] The refrigeration system according to the invention allows the required operation conditions of the

system to be set so that it matches the needs of the user, particularly the evaporating pressure of the first refrigerant, which determines the corresponding saturated evaporating temperature. Due to the refrigeration systems ability to work at high operation pressures, it is possible to select a pressure in the evaporators that corresponds to a saturation temperature in the range from -44°F to -10°F.

[0011] Furthermore, the resulting system is significantly safer than ammonia systems due to replacing ammonia in the manufacturing areas with CO₂, which is significantly less toxic. This makes the refrigeration system of the invention particular suitable for the food industry. In addition the refrigeration system has shown to be competitive in capital cost and energy efficiency.

[0012] In another aspect, this invention provides a method of refrigeration. The method of refrigeration comprises

providing a refrigeration system according to any of the proceeding claims, providing the first and second refrigerant,

circulating the first refrigerant in the first refrigeration circuit whereby the first refrigerant liquid is evaporated in the first evaporator to provide a refrigeration effect, compressing the evaporated first refrigerant in the compressor, condensing evaporated first refrigerant to a liquid form in the first condenser, and returning the first refrigerant liquid to the first evaporator through a control valve.

circulating the second refrigerant in the second refrigeration circuit whereby the second refrigerant liquid is evaporated in the second evaporator to provide a refrigeration effect cooling the first condenser, compressing the evaporated second refrigerant in the compressor, and condensing evaporated second refrigerant to a liquid form in the condenser, and returning the second refrigerant liquid to the second evaporator through a control valve

characterised in that

the first refrigerant provided is CO₂ and the second refrigerant is a refrigerant having lower pressure corresponding to its saturation temperature than CO₂, and the evaporation of the CO₂ in the first evaporator takes place at an operating pressure above 120 psig.

[0013] The preferred operation conditions mentioned in relation to the refrigeration system according to the invention apply similarly to the method of the invention.

Detailed Description of Preferred Embodiments of the Invention

[0014] Embodiments of the invention are now described, by way of example only.

[0015] It is preferred that the operation pressure throughout the first refrigeration circuit is between 120 psig and 1056 psig. 1056 psig is the critical point for

CO₂, above which CO₂ cannot be condensed to liquid. A more preferred operation pressure through out in the first refrigeration circuit is in the range from 120 psig to about 580 psig. Operating the system in indicated ranges improves the energy efficiency of the cascade system, by allowing the evaporators to operate at a pressure that most suits the needs of the medium being cooled and to optimise the heat transfer conditions between the first and second refrigerants.

[0016] The first compressor 4 advantageously has an operation pressures above 325 psig. at the discharge of the compressor 4, preferably from 325 psig to about 580 psig, more preferably from 350 psig to about 425 psig. With the above mentioned operation pressures in the first circuit and the first compressor respectively, a particular energy efficient cascade refrigeration system is obtained.

[0017] In a preferred embodiment of the invention the operation pressure throughout the second refrigeration circuit is below 350 psig. so that standard refrigeration components can be used. The higher operating pressure of the CO₂ circuit allows selection of the optimum conditions for heat exchange between the CO₂ and the second refrigerant in the cascade heat exchanger, improving system efficiency.

[0018] Furthermore it is preferred that the first evaporator is operating at pressures from 120 psig to about 580 psig, more preferably from 120 psig to about 180 psig, most preferably from about 122 to about 160 psig.

[0019] Advantageously, the first refrigeration circuit comprises means for cooling the first refrigerant liquid subsequent to its condensing in the first condenser. The means for cooling the first refrigerant may comprise an Economiser vessel connected to the first compressor allowing vapour resulting from the cooling to be forwarded to the compressor. Alternatively, a heat exchanger may be used for cooling the first refrigerant liquid. In this way the refrigeration systems efficiency is improved by cooling the liquid CO₂ by evaporation in the economiser vessel or in the heat exchanger prior to going to the low pressure part of the CO₂ system, with the resulting vapour going to the economiser port on the CO₂ compressor. It has been found that it is particular advantageous to apply these measures to the first refrigeration to make it more energy efficient.

[0020] Further improvement of the systems energy efficiency may be obtained with the CO₂ compression achieved by 2 or more compressors operating in series. In particular it has been found that the energy efficiency is improved by using 2 or more compressors in the first refrigeration circuit. Advantageously, the CO₂ vapour is cooled and desuperheated between the compressors in an intercooler vessel or heat exchanger. At the same time the liquid refrigerant may be cooled to an intermediate temperature between that of the High Pressure CO₂ Vessel and the Low Pressure CO₂ Vessel. This multi-stage compression technique improves overall system efficiency.

[0021] In a preferred embodiment of the invention, the operating pressure of the second evaporator corresponds to a saturation temperature that is as close as possible to the saturation temperature equivalent to the pressure of the first refrigerant in the first condenser. In preference, this temperature difference should be as low as 5 °F (2°C). The advantage of this is that the pressure in the second evaporator is as high as possible, which improves system efficiency.

[0022] The invention will now be discussed in further details with reference to Figure 1 showing an example of a preferred refrigeration system according to the invention.

[0023] Figure 1 shows a refrigeration system having a first refrigeration circuit 17 and a second refrigeration circuit 18 arranged in cascade. The first refrigerant is according to the invention CO₂.

[0024] Liquid CO₂ is by means of a pump 2 from a low-pressure CO₂ vessel 1 sent to one or more evaporators 3 operating in parallel, where it evaporates, removing heat (Q) from the medium being cooled. The pumping rate to the evaporators is at least equal to the evaporation rate; but could be more to ensure wetting in the CO₂ side of each evaporator. Alternatively, the liquid supply could be achieved without a pump, using natural circulation.

[0025] The evaporators 3 may be of any conventional type, but designed for working pressures, corresponding to the needs of the medium being cooled e.g. plate evaporators, fin-coil units, scraped surface evaporators, tubular coolers

[0026] Subsequently the mixture of CO₂ liquid and vapour returns to the Low-pressure CO₂ vessel 1, where they are separated. The liquid is then available to be sent back to the evaporators. The CO₂ vapour goes to a CO₂ compressor 4, where it is compressed to a pressure preferably exceeding 325 psig, but less than the CO₂ critical point (1056 psig). This compressor 4 may advantageously be fitted with an "economiser port" to take additional vapour from a CO₂ economiser vessel 7 to improve system efficiency.

[0027] The compressors 4 may be any type suitable for the required duty. However, the preferred compressor type would be an oil injected screw compressor with gravity and coalescing oil separator. Suitable compressors may be obtained from Mycom, Sabroe or Kobelco. If needed tertiary oil separation may be provided using activated carbon or similar. An example of a compressor type, which may be suitable for the present application, is a natural gas compressor. Adaptation of the natural gas compressor may be needed e.g. adaptation of sealing materials, oil separation, oil injection points, removing explosion proofing.

[0028] The compressed CO₂ is then cooled and condensed in a cascade heat exchanger 5, which is cooled by the evaporation of a second refrigerant that can operate at higher saturation temperatures than CO₂ with pressures below 350 psig to permit the use of standard

commercial refrigeration components in the second refrigerant circuit. A plate type heat exchanger is preferred to minimise the temperature difference between the condensing CO₂ and the evaporating second refrigerant - improving system efficiency. There may be multiple cascade heat exchangers in parallel. Suitable plate type heat exchangers are for example available from Alfa Laval.

[0029] The condensed CO₂ is stored in a High-pressure CO₂ Vessel 6, until it is needed in the Evaporators 3. Alternatively, storage could be in the Low Pressure CO₂ Vessel 1 or CO₂ Economiser vessel 7. In this case, a control valve is needed after the cascade heat exchanger 5 to maintain pressure in the cascade heat exchanger 5 (the first condenser). This control valve has a similar function to 19.

[0030] When needed in the Low Pressure part of the system, liquid CO₂ is fed to the low-pressure CO₂ vessel 1 through a control valve 19 where pressure is decreased to that of the low-pressure vessel 1, with a portion of the CO₂ evaporating to cool the liquid. The resulting liquid/vapour mixture flows to the low-pressure vessel 1, where the liquid and vapour components are separated. The vapour goes to the CO₂ compressor 4 with the vapour from the evaporator 3. This completes the closed circulation of the CO₂.

[0031] To improve CO₂ circuit efficiency, the liquid may first go through a control valve 19 to a CO₂ economiser vessel or heat exchanger 7, operating at a pressure between that of the high-pressure CO₂ vessel 6 and the low-pressure CO₂ vessel 1. At this intermediate pressure, some of the liquid CO₂ evaporates, cooling the remainder of the liquid. The vapour is separated from the liquid and goes to the "economiser port" on the compressor 4.

[0032] Optionally, the high-pressure CO₂ vessel 6 and CO₂ economiser vessel 7 may also have connected additional evaporators 9 and 8 respectively to provide cooling at operating temperatures higher than the main evaporators 3. Method of liquid and vapour circulation is the same as for 3.

[0033] To control the pressure in the CO₂ circuit, the vessels, evaporators and heat exchangers may be fitted with safety relief valves and/or other pressure activated devices to release vapour from the CO₂ circuit, reducing the pressure. Alternatively, any or each vessel, evaporator and heat exchanger in the CO₂ circuit may be connected to a small package refrigeration system 10, to control the pressure by cooling the CO₂ when the main plant is shut down. By this method, it is possible to build the CO₂ circuit for safe working pressures below that which would otherwise be required, reducing the capital cost.

[0034] On small CO₂ circuits, the pressure control during shutdown may also be achieved by installing an additional vessel that permits all of the CO₂ in the circuit to be stored as vapour at pressures below the safe working pressure of the system usually referred to as a "fade

out" vessel.

[0035] As a variation, the single stage CO₂ compressor 4 may be replaced by 2 or more compressors operating in series, with the vapour being cooled and desuperheated between them (i.e. multi-stage operation with intercooler). The advantage of this is to improve the system efficiency.

[0036] The second refrigeration circuit 18 comprises a second liquid refrigerant. The second refrigerant is fed from a low-pressure vessel 11, to the cascade heat exchanger 5, where it evaporates, cooling and condensing the CO₂. The liquid second refrigerant feed could be pumped or by natural circulation. Feed rate will at least equal the evaporation rate, but could be higher to ensure wetting of the second refrigerant side of the heat exchanger 5.

[0037] The mixture of second refrigerant liquid and vapour returns to the low-pressure vessel 11, where they are separated. The liquid is then available to be sent back to the cascade heat exchanger 5. The separated second refrigerant vapour goes to the compressor 12, where it is compressed to an appropriate pressure that permits condensing in the condenser 13. This compressor may also be fitted with an "economiser port" to take additional vapour from an economiser vessel 15 to improve system efficiency. There may be multiple compressors operating in parallel if necessary.

[0038] The compressed second refrigerant is cooled and condensed in the second condenser 13, which is cooled by air, water or other suitable cooling medium. The rejected heat may be recovered and used for other purposes to improve overall system efficiency. There may be multiple condensers 13 in parallel.

[0039] The condensed second refrigerant may then be stored in a high-pressure vessel 14, until it is needed in the cascade heat exchanger 5. Alternatively, storage could be in the low-pressure vessel 11. In this case, a control valve is needed after the condenser 13 to maintain pressure in the second condenser 13. This control valve has a similar function to 19.

[0040] When needed in the low pressure part of the second refrigerant system, liquid second refrigerant goes to the low pressure vessel 11 through a control valve 20 where pressure is decreased to that of the low-pressure vessel 11, with a portion of the second refrigerant evaporating to cool the liquid. The resulting liquid/vapour mixture flows to the low-pressure vessel 11, where the liquid and vapour components are separated. The vapour goes to the second refrigerant compressor 12 with the vapour from the second evaporator 5. This completes the closed circulation of the second refrigerant.

[0041] To improve second refrigerant circuit efficiency, the liquid may first go through a control valve 20 to an economiser vessel or heat exchanger 15, operating at a pressure between that of the high-pressure vessel 14 and the low-pressure vessel 11. At this intermediate pressure, some of the liquid evaporates, cooling the re-

mainder of the liquid. The vapour is separated from the liquid and goes to the "economiser port" on the compressor 12.

[0042] Optionally, the low-pressure vessel 11, may also have connected evaporators 16 to provide cooling at temperatures higher than the operating conditions of the CO₂ circuit. Method of liquid and vapour circulation is the same as for the CO₂ evaporators 3.

[0043] The preferred second refrigerant is Ammonia. However, it may be any available refrigerant that can operate at acceptable pressures coinciding with the design saturated condensing temperature of the condenser 13. Examples of other suitable refrigerants are HFC-134A.

[0044] Except for the cascade heat exchanger, which must be designed for the pressure of the CO₂ circuit, the preferred construction method of the second refrigerant circuit is using all standard available refrigeration components. Suitable components may e.g. be obtained from Mycom, York, and GEA/Grasso. High-pressure heat exchangers are e.g. known from the petrochemical industry. Such high-pressure heat exchangers may be adapted to include circuiting to handle evaporating and condensing refrigerants etc.

[0045] As a variation, the single stage compressor 12 may be replaced by 2 or more compressors operating in series, with the vapour being cooled and desuperheated between them (i.e. multi-stage operation with intercooler). The advantage of this is that system efficiency is improved.

[0046] The refrigeration system according to the invention may be applied in any freezers or coolers. The refrigeration system has been found to be particular suitable for an application in food freezers due to its safety, efficiency and environment friendly operation. The following are examples of applications in which the refrigeration system is particular suitable:

Plate freezers are freezers wherein the product to be frozen placed between plates and held at low temperatures until they are frozen. The product is usually packed in boxes that are loaded and discharged by an automatic loading and discharging system. The heat transfer is by direct contact between the plates and the boxed product. These plates are a first evaporation circuit. The cooling is an effect of CO₂ evaporating inside the plates. A preferred evaporation pressure is about 122 psig corresponding to a saturation temperature of -43 °F (-42 °C). The whole equipment above is contained inside an insulated enclosure.

Air blast freezers may also provide refrigeration based on the refrigeration system of the invention. In these freezers the product is conveyed through the freezer on a chain mesh or similar conveyor. This conveyor could be a spiral or straight belt. The product is cooled by re-circulated air, cooled by a fin-coil air cooler by evaporating CO₂ in a first re-

frigeration circuit. The fin-coil air coolers are cooled by CO₂ evaporating inside the coils. The evaporation pressure is about 122 psig corresponding to a saturation temperature of -43 °F (-42 °C).

Another advantageous application of the invention is for refrigeration in scraped surface coolers. Scrape surface coolers are coolers wherein liquid or paste product is cooled as it is pumped through a cylindrical barrel. Inside the barrel is a rotating scraper that agitates the product and removes frozen product from the barrel walls. The barrel is cooled by CO₂ evaporating inside the surrounding jacket. CO₂ circulation is achieved by natural thermosiphon effect or pumped overfeed. A preferred evaporation pressure is about 158 psig corresponding to a saturation temperature of -30 °F (-34 °C). Product temperature may be controlled by varying the CO₂ pressure in the barrel.

Other examples for which the refrigeration system according to the invention conveniently may be applied are fluid bed freezers, contact band freezers, cold storage and tempering rooms etc.

Claims

1. A refrigeration system comprising

a first closed refrigeration circuit (17) for containing a first refrigerant, comprising a first evaporator (3) for evaporating first refrigerant liquid, a first compressor (4) for compressing first refrigerant vapour, a first condenser (5) for condensing the first refrigerant vapour, and a first control valve (19) for controlling the pressure difference between the high pressure side and the low pressure side of the first circuit, a second closed refrigeration circuit (18) for containing a second refrigerant, comprising a second evaporator (5) for evaporating second refrigerant liquid, a second compressor (12) for compressing second refrigerant vapour, a second condenser (13) for condensing the second refrigerant vapour, and a second control valve (20) for controlling the pressure difference between the high pressure side and the low pressure side of the second circuit, and a cascade heat exchanger (5) comprising the first condenser and the second evaporator arranged so that the first condenser is cooled by means of the evaporation of the second liquid refrigerant in the second evaporator,

characterised in that said first refrigerant consists substantially of CO₂ and the first evaporator (3) is operating at pressures above 120 psig.

2. A refrigeration system according to claim 1, in which

the operation pressure throughout the first refrigeration circuit is between 120 psig and 1056 psig.

3. A refrigeration system according to any of claims 1 and 2, in which the first compressor (4) has an operation pressures above 325 psig at the discharge of the compressor (4).
4. A refrigeration system according to any of the claims 1 to 3, in which the first refrigeration circuit comprises means for cooling the first liquid refrigerant subsequent to its condensing in the first condenser (5)
5. A refrigeration system according to claims 1 to 4, in which the means for cooling the first liquid refrigerant comprises an economiser vessel (7) connected to an economiser port on first compressor (4) allowing vapour resulting from the cooling to be forwarded to the compressor (4).
6. A refrigeration system according to any of claim 4 and 5, the means for cooling the first liquid refrigerant comprises the heat exchanger and means for conveying vapour resulting from the cooling to compressor (4).
7. A refrigeration system according to any of claims 1 to 4 and 6, in which the first closed refrigeration circuit (17) comprises two or more compressors operating in series.
8. A refrigeration system according to claim 7, in which the first refrigeration circuit (17) comprises an inter-cooler vessel and/or a heat exchanger disposed between the compressors for the cooling and desuperheating of first refrigerant vapour.
9. A refrigeration system according to claim 8, in which means are provided for cooling the first refrigerant liquid to a temperature between the temperatures of the first refrigerant liquid in the high pressure vessel (6) and in the low pressure vessel (1).
10. A refrigeration system according to any of claims 1 to 9, in which the first evaporator (3) is operating at pressures from 120 psig to about 580 psig, preferably from 120 psig to about 180 psig.
11. A refrigeration system according to any of claims 1 to 9, in which the operating pressure of the second evaporator (5) corresponds to a temperature difference between that of the second evaporator (5) and the first condenser (5) is no more than 5°F (2°C).
12. A refrigeration system according to any of claims 1 to 11, in which the first closed refrigeration circuit (17) comprises a refrigeration system (10) to control

the pressure in the first refrigeration circuit (17) by cooling the CO₂ when the refrigeration system is not being used.

13. A method of refrigeration comprising

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providing a refrigeration system according to any of the proceeding claims, providing the first and second refrigerant,

circulating the first refrigerant in the first refrigeration circuit whereby the first refrigerant liquid is evaporated in the first evaporator (3) to provide a refrigeration effect, compressing the evaporated first refrigerant in the compressor (4), condensing evaporated first refrigerant to a liquid form in the first condenser (5), and returning the first refrigerant liquid to the first evaporator (3) through a control valve (19), circulating the second refrigerant in the second refrigeration circuit whereby the second refrigerant liquid is evaporated in the second evaporator (5) to provide a refrigeration effect cooling the first condenser (5), compressing the evaporated second refrigerant in the compressor (12), and condensing evaporated second refrigerant to a liquid form in the condenser (13), and returning the second refrigerant liquid to the second evaporator (5) through a control valve (20),

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characterised in that

the first liquid refrigerant provided is CO₂ and the second liquid refrigerant is a refrigerant having lower pressure corresponding to it's saturation temperature than CO₂, and the evaporation of the CO₂ in the first evaporator (3) takes place at an operating pressure above 120 psig.

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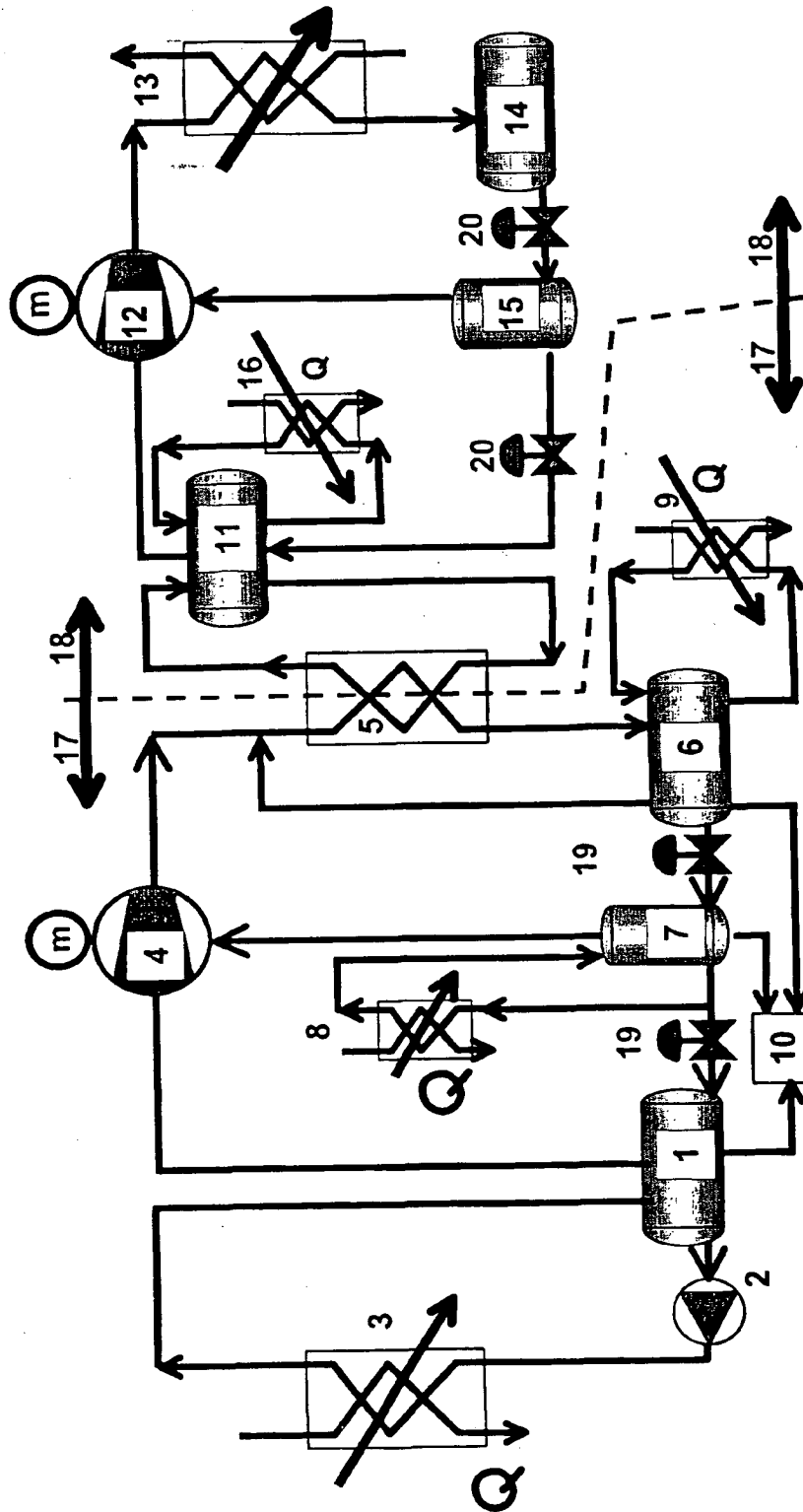


Fig 1



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EUROPEAN SEARCH REPORT

Application Number
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EPO FORM 1603 (03/02) (P4/C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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